

Fertilizer & Pesticide

Plant Nutrients Cycling Processes

Crops require proper amounts of nutrients at the right time to grow. Three nutrients, carbon (C), hydrogen (H), and oxygen (O), make up about 95% of plant dry matter and are supplied in large amounts from atmospheric gases and water. Nitrogen (N), phosphorus (P) and potassium (K) come from the soil. These nutrients are most likely to be deficient for crops in Montana. The secondary nutrients, calcium (Ca), magnesium (Mg), and sulfur (S) and micronutrients zinc, iron, manganese, copper, molybdenum, chloride and boron are also needed by plants in lesser amounts, but are deficient less often.

Nutrients contained in plant tissue and organic matter are recycled in the soil through decomposition processes. These elements are taken up by plants and microorganisms, incorporated into plant and animal tissue, released, changed, and involved in a variety of soil transformations. Although soil microbes as a group, especially bacteria, are adapted to a wide range of living conditions, some generalizations can be made about the conditions they require, particularly with "typical" agricultural soils. In general, microorganisms involved in organic matter decomposition:

- ✓ exist mostly in surface soil layers, to depths determined by aeration and the presence of organic matter
- ✓ are stimulated by moist, warm conditions and an organic food supply
- ✓ multiply very rapidly when conditions are suitable
- ✓ have the capacity to tolerate unsuitable conditions by becoming dormant and
- ✓ release nutrients tied up in organic matter

The amount of N in soil water as ammonium and nitrate is usually less than 2 percent of the total soil N (except following recent applications of N fertilizer or manure). The reactions and pathways making up the cycle is different for each nutrient. For example, both N, C, O and S are contained in air and alternate between solid and gaseous forms. The processes involved in nutrient cycling determine the rate of nutrient release in the soil, and the fate of applied nutrients.

Nutrients are added to the crop/soil system by adding fertilizers, manure, sludge, crops, precipitation, and irrigation water. Nutrients can also be lost from the cycle through leaching, erosion, transformations, and crop harvest. In particular, N, P and K, are removed in large quantities by crop harvest, and should be monitored and replaced when needed through use of fertilizers or other sources of readily available nutrients. An understanding of nutrient cycling pathways, rates of change, inputs, and losses provide management opportunities to benefit crop production. This fact sheet discusses the cycling of major plant nutrients and relationships to crop nutrient supply.

Carbon:nitrogen ratio

The ratio of C to N in soil or organic materials indicates the

rate at which organic material will decay. The C:N ratio of a soil is fairly stable in the absence of major organic inputs — usually between 10:1 and 12:1 for most agricultural soils.

Organic materials containing low N have high C:N ratios (for example, 90:1 for sawdust or tree bark). Conservation tillage systems may also influence N requirements. Soil organisms require N to decompose organic matter and crop residues, and the more organic material present, the more N required. In the presence of low-N materials, microorganisms compete with plants for available N, and soil N may be depleted for a time. As the organic material is converted to humus, C is released as carbon dioxide (CO₂), and the C:N ratio of the soil decreases. Ammonium which is not immobilized by microorganisms is available for nitrification, which results in the production of nitrate.

Ammonium and nitrate are highly soluble. Nitrate is not adsorbed to soil colloids so, it is subject to leaching. Nitrate can also be converted to N gases by soil microbes and lost to the air (denitrification). Denitrification is encouraged by poor soil aeration, where oxygen is limiting (saturated soils), as bacteria obtain oxygen from NO₃⁻ and release gas. Nitrogen is also lost through runoff, erosion, leaching, and harvest.

Seventy-eight percent of the atmosphere is N₂ gas that cannot be used directly by plants. This represents a virtually unlimited supply of N when converted to a usable form. Atmospheric N is used in the manufacture of N fertilizers. It is also made available to plants through the process of N fixation, carried out by soil bacteria. Biological N fixation is the principal means by which atmospheric N enters the soil-plant system. Legumes, such as peas, beans, clovers, and alfalfa have a unique association (symbiotic) with N-fixing bacteria that colonize their roots and supply plant-available N. Some free-living bacteria also fix N. Nitrogen fixation represents a significant N input that can reduce the need for N fertilizers.

Phosphorus Cycle

Phosphorus is contained in rock minerals, plant and animal tissue, water, and soil. Plants take up P only in the form of the phosphate ion, HPO₄⁻ or H₂PO₄⁻, which at any given time represents a very small proportion of total soil P. Aside from that applied as fertilizer, much plant-available P is from organic matter decomposition. In this way, P is cycled between plants, animals and soil.

In the soil, P exists in many forms, most of which is unavailable to plants. Unavailable P is tied up in insoluble, organic and inorganic compounds, or tightly bound to clay surfaces. The P reserve most readily available to replace P removed by plants is referred to as "labile" P. This portion of the soil P is very important to soil fertility and is the quantity normally measured in a soil test. The rate at which P is released depends on the forms present, soil chemistry, temperature, and soil pH, among other variables.

Only 20 to 30 percent of the P added as fertilizer is used by a crop in a given year. A large proportion of added P is "fixed" (made

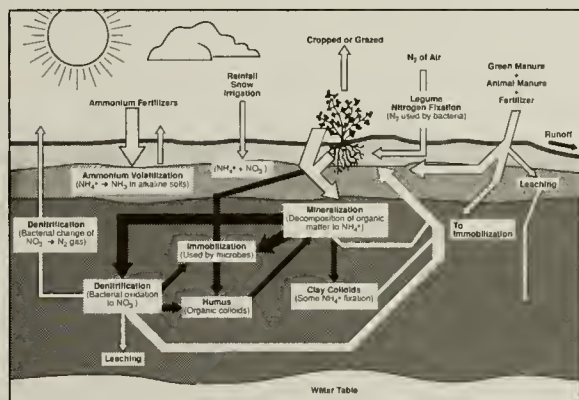


FIGURE 2 Nitrogen cycle—many transformations determine the fate of soil N (Jacobsen, 1991).

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less available) in the soil. In high-calcium soils, P is fixed primarily by combining with calcium carbonate (lime). Over the long-term, most of the fixed P is available. While not considered "fixed", some added P is also tied up by microorganisms (immobilization).

Most soil P is complexed with and bound to soil particles, organic compounds, and cations. Little P exists in solution at any given time, frequently less than 1 ppm, so that there is virtually no possibility of leaching. The major avenue of P loss from the system is through soil erosion and, because P tends to be concentrated in the surface soil, erosion losses can be large.

Potassium Cycle

Potassium is generally very abundant in the soil. It is not uncommon to find soils with 40 to 60 thousand pounds of K in the top six inches of the soil. However, most of this is contained in clay minerals and is not readily available to plants. In the K cycle, the bulk of K is contained in living plant tissue and unweathered (primary) rock minerals. Within the plant, K exists in simple forms, and rapidly leaches out of dead plant tissue and into the soil.

Only 1 to 2 percent of the total soil K exists in soil water at any given time and leaching losses are generally low due to adsorption on exchange sites. However, leaching can still be a problem on sandy soils or where large amounts of K fertilizer are applied. In the soil, potassium occurs in relatively unavailable forms in unweathered rock minerals (amounts released in one growing season are negligible), slowly available forms in clay particles, and exchangeable (readily available) K. The greatest potential for loss of exchangeable K is through soil erosion.

Movement of Nutrients in Soil

The mobility of a nutrient determines the potential for losses through leaching or runoff. The loss of nutrients is not only uneconomical and may reduce crop yields, but may be a source of ground and/or surface water impairment.

Nitrogen movement

Most plant-available N is in the form of nitrate (NO_3^-), which exists primarily in soil water and is, therefore, extremely mobile in soil. Ammonium (NH_4^+) is also highly soluble, but because of its positive charge, tends to be adsorbed on clay and organic matter particles and is held in the root zone. The depth to which nitrate moves depends on amounts of precipitation, irrigation and the water-holding capacity of the soil.

Nitrate loss through leaching occurs when rainfall and irrigation exceed the water holding capacity of the soil. Once leached out of the crop root zone, nitrate can enter ground water. Factors determining the leaching potential of a given soil are: the initial water content, soil texture and coarse fragment content, presence of an impermeable layer, crop selection, and crop rooting depth.

In dryland soils, the highest nitrate concentrations often occur in fall, in fallow soils, due to the cumulative mineralization of organic matter over summer. Fall rains then provide an opportunity for nitrate leaching. Under most circumstances, accumulated fall precipitation alone is not sufficient to move nitrate out of the rooting zone.

Statewide nitrate losses through leaching from cropland are estimated to be generally less than 25 pounds per acre. Losses of this magnitude are not thought to pose a threat to ground water

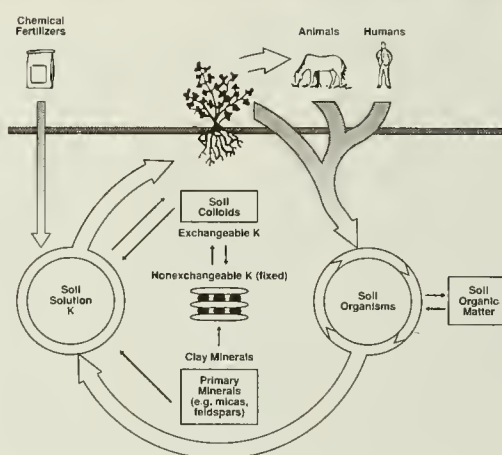


FIGURE 2. Phosphorus cycle- most P must be liberated from mineral and organic compounds in order to be used by plants (Tisdale, 1985).

quality. However, in localized areas losses may be much higher, especially where intensive, irrigated farming is practiced. Improper handling and storage of nutrient sources also represents a potentially detrimental, concentrated nitrate source.

Unfortunately, fertilizers represent only one of many possible sources of nitrate in ground water. Excess ground water nitrate is often caused by high-density animal operations or septic systems. Certain areas are underlain with geologic deposits high in nitrate that can leach if irrigated or summer fallowed. Organic wastes, such as farm manure, sewage sludge, food processing wastes and crop residues, which are normally good sources of plant nutrients, can become pollution sources if handled improperly or placed near a well. One or more nitrate sources may be responsible for localized instances of ground water pollution.

Phosphorus movement

Phosphorus ions are negatively charged like nitrate, but behave differently by reacting with clays, organic matter, cations, and inorganic compounds, most notably calcium carbonate, to form insoluble compounds. For this reason, very little of the total soil P exists in solution at any given time, making it a very immobile nutrient. As a result, little if any P is transferred from the surface to the subsoil or ground water by leaching.

Phosphorus is bound to soil particles and concentrated in the surface soil where organic matter and fertilizers are concentrated. Phosphorus can easily be lost through runoff and soil erosion. Phosphorus lost in runoff represents a loss of productivity, waste of fertilizer dollars, and a threat to surface water quality. On sloping fields or coarse-textured soils, management practices must be implemented to keep runoff and sediment from entering streams and lakes.

Phosphorus may move downward more freely in soils that are waterlogged or saturated for extended periods. In these soils, more P exists in dissolved, organic forms. Likewise, regular additions of organic materials (residue or manure) increase the amount of mobile phosphate in the soil system.

Potassium movement

As a cation, K^+ is strongly adsorbed on soil colloids. At any given time the potential for movement or leaching is small. While there is little downward movement of K in most agricultural soils, leaching can occur in sandy soils, and other soils with very low cation exchange capacity (CEC). Over time, K has been observed to move several feet in sandy soils. Excess added K may not be adsorbed and may be subject to leaching or fixation in unavailable forms. Under appropriate fertilizer rates, K leaching should be minimal. Potassium impairment of ground water is not a health threat.

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